# Increasing laser-driven THz emission with sawtooth pulse profiles

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Broadband Terahertz (THz) sources have important applications in molecular physics, chemistry, material sciences and security. Lying at the boundary between electronics and optics, the THz frequency range, sometimes referred to as *THz gap*, is not easy to access and fields emitted in this band need to be strong enough to serve in current applications. Innovative setups recently proposed to use the electron plasma resulting from the ionization of gases by femtosecond laser pulses, which provide higher breakdown thresholds, broader spectral ranges and better tunability in the THz and mid-infrared ranges [1]. With two-color laser pulses, THz field amplitudes approaching the GV/m level and energies of a few $\mu$J can be obtained through local photocurrents. Along this process, free electrons, extracted from atoms in sharp attosecond-long steps by tunnel ionization, are accelerated in the laser field and create a net macroscopic current that contains low frequency components and is responsible for the observed THz emission.

To describe this phenomenon, the *local current* (LC) theory assumes that the radiated field is proportional to the derivative of the free electron current [2] and highlights that THz radiation increases with the electric field strength and the free electron velocity in the vicinity of the ionization instants. As the electron velocity is related to the whole pump waveform, one may thus achieve higher THz yields by optimizing the optical pulse profile. We demonstrate that an optimal waveform is the sawtooth profile, which, in theory, can increase the THz generation up to two orders of magnitude compared to standard two-color pulses. By approximating such a profile by a *small* number of colors [see Fig. 1(a)], the resulting pulse profile preserves very well the properties of the ideal sawtooth, already yielding impressive gains. Illustrating these gains computed from the LC theory, Fig. 1(b) shows the THz yield as a function of the number of colors for a fixed degree of ionization in argon, emphasizing that the four-color approximation of a sawtooth waveform increases the THz yield by $\sim 4$ compared with a two-color configuration. Analogously, its inset reveals a spectacular gain of 20 when the pump pulse intensity is fixed.

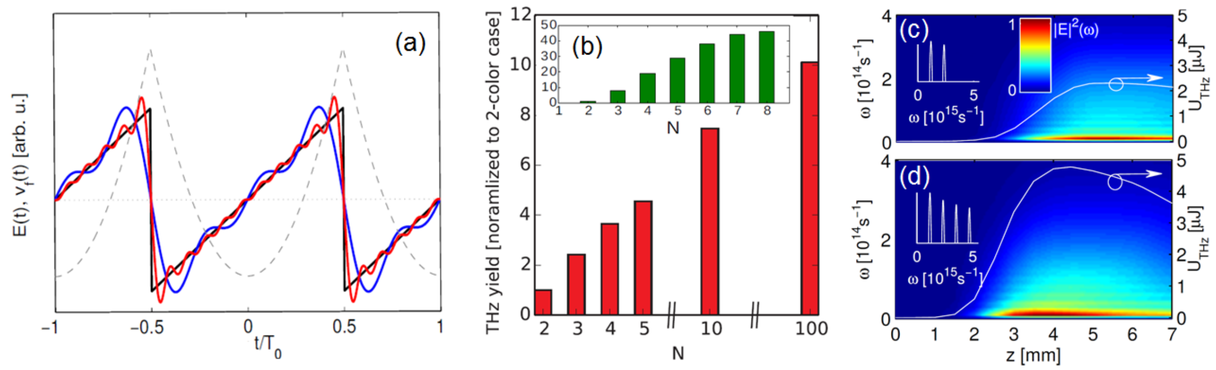


Figure 1: (a) Ideal sawtooth (black curve), electron velocity (dashed), three-color (blue) and ten-color (red) approximations. (b) THz yield vs number of colors for fixed ionization degree (10% of neutral density, red bars) and pulse intensity (100 TW/cm$^2$, green bars) in argon for a 1600-nm, 40-fs pump. THz spectra (left axis) and energies (right axis) for (c) two-color and (d) four-color sawtoothlike 3D pulses with 300-$\mu$J energy focused in Ar.

We finally carried out comprehensive 3D simulations of 300 $\mu$J focused pulses to confirm the LC predictions, taking into account propagation and multidimensional effects. Results from these simulations are shown in Figs. 1(c,d), for which the ionization degree reached at focus remains comparable (not plotted). Achieving 5 $\mu$J THz energy with four-color sawtoothlike pulses, we obtain a gain factor of 2.5, which reasonably agrees with Fig. 1(b), and report an unprecedented THz conversion efficiency of 2%.

## References


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